Chapter 15: Sound

Practice Problems

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1. Sound with a frequency of 261.6 Hz travels through water at a speed of 1435 m/s. Find its wavelength in water.

$v = \lambda f$ so $\lambda = \frac{v}{f} = \frac{1435 \text{ m/s}}{261.6 \text{ Hz}} = 5.485$ m

2. Find the frequency of a sound wave moving in air at room temperature with a wavelength of 0.667 m.

$v = \lambda f$ so $f = \frac{v}{\lambda} = \frac{343 \text{ m/s}}{0.667 \text{ m}} = 514$ Hz

3. The human ear can detect sounds with frequencies between 20 Hz and 16 kHz. Find the largest and smallest wavelengths the ear can detect, assuming the sound travels through air with a speed of 343 m/s at 20°C.

From $v = \lambda f$ the largest wavelength is

$\lambda = \frac{v}{f} = \frac{343 \text{ m/s}}{20 \text{ Hz}} = 17$ m; the smallest is

$\lambda = \frac{v}{f} = \frac{343 \text{ m/s}}{16000 \text{ Hz}} = 0.021$ m.

4. a. What is the frequency of sound in air at 20°C having a wavelength equal to the diameter of a 15-inch (38 cm) "woofer" loudspeaker?

Woofer diameter 38 cm,

$f = \frac{v}{\lambda} = \frac{(343 \text{ m/s})}{(0.38 \text{ m})} = 0.90$ kHz

b. What is the frequency of sound in air at 20°C having a wavelength equal to the diameter of a 3-inch (7.6 cm) diameter "tweeter"?

Tweeter diameter 7.6 cm

$f = \frac{v}{f} = \frac{(343 \text{ m/s})}{(0.076 \text{ m})} = 4.5$ kHz

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5. A 440-Hz tuning fork is held above a closed pipe. Find the spacings between the resonances when the air temperature is 20°C.

Resonance spacing is $\frac{\lambda}{2}$ so using $v = \lambda f$ the resonance spacing is

$\frac{\lambda}{2} = \frac{v}{2f} = \frac{343 \text{ m/s}}{2(440 \text{ Hz})} = 0.390$ m.

6. The 440-Hz tuning fork is used with a resonating column to determine the velocity of sound in helium gas. If the spacings between resonances are 110 cm, what is the velocity of sound in He?

Resonance spacing = $\frac{\lambda}{2} = 1.10$ m so

$\lambda = 2.20$ m and

$v = f\lambda = (440 \text{ Hz})(2.20 \text{ m})$

$= 968$ m/s.

7. The frequency of a tuning fork is unknown. A student uses an air column at 27°C and finds resonances spaced by 39.2 cm. What is the frequency of the tuning fork?

From the previous example problem $v = 347$ m/s at 27°C and the resonance spacing gives $\frac{\lambda}{2} = 0.392$ m or $\lambda = 0.784$ m.

Using $v = \lambda f$, $f = \frac{v}{\lambda} = \frac{347 \text{ m/s}}{(0.784 \text{ m})} = 443$ Hz.

8. The auditory canal, leading to the eardrum, is a closed pipe 3.0 cm long. Find the approximate value (ignoring end correction) of the lowest resonant frequency.

$l = \frac{\lambda}{4}$, $v = \lambda f$, so

$f = \frac{v}{4l} = (343 \text{ m/s})(4 \times 0.03 \text{ m}) = 2.9$ kHz

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9. A bugle can be thought of as an open pipe. If a bugle were straightened out, it would be 2.65 m long.

The lowest resonant frequency of an open pipe corresponds to the wavelength λ_1, where $\frac{\lambda_1}{2} = L =$ length of pipe. Further resonances are spaced $\frac{\lambda}{2}$ apart, giving the series of resonance wavelengths $L = \frac{\lambda_1}{2}, 2\left[\frac{\lambda_2}{2}\right], 3\left[\frac{\lambda_3}{2}\right], \ldots$.

a. If the speed of sound is 343 m/s, find the lowest frequency that is resonant in a bugle.

$\lambda_1 = 2L = 2(2.65\ \text{m}) = 5.30$ m so that the lowest frequency is

$$f_1 = \frac{v}{\lambda_1} = \frac{343\ \text{m/s}}{5.30\ \text{m}} = 64.7\ \text{Hz}$$

b. Find the next two higher resonant frequencies in the bugle.

$$f_2 = \frac{v}{\lambda_2} = \frac{v}{L} = \frac{343\ \text{m/s}}{2.65\ \text{m}} = 129\ \text{Hz}$$

$$f_3 = \frac{v}{\lambda_3} = \frac{3v}{2L} = \frac{3(343\ \text{m/s})}{2(2.65\ \text{m})} = 194\ \text{Hz}$$

10. A soprano saxophone is an open pipe. If all keys are closed, it is approximately 65 cm long. Using 343 m/s as the speed of sound, find the lowest frequency that can be played on this instrument (ignoring end corrections).

The lowest resonant frequency corresponds to the wavelength given by $\frac{\lambda}{2} = L$, the length of the pipe. $\lambda = 2L = 2(0.65\ \text{m}) = 1.30$ m so $f = \frac{v}{\lambda} = \frac{343\ \text{m/s}}{1.30\ \text{m}} = 260$ Hz. Since the saxophone is an open pipe,
$\lambda_{max} = 2 \times (\text{pipe length}) = 2(0.65\ \text{m})$
$= 1.30$ m

$$f_{min} = \frac{v}{\lambda_{max}} = \frac{343\ \text{m/s}}{1.30\ \text{m}} = 260\ \text{Hz}$$

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11. A 330-Hz and a 333-Hz tuning fork are struck simultaneously. What will the beat frequency be?

Beat frequency $= |f_2 - f_1|$
$= |333\ \text{Hz} - 330\ \text{Hz}|$
$= 3$ Hz

12. A student has two tuning forks, one with a frequency of 349 Hz and the other with an unknown frequency. When struck together, the tuning forks produce three beats a second. What are the possible frequencies of the unknown tuning fork?

The frequency of the second fork could be either
$f_2 = f_1 + f_{beat} = 349\ \text{Hz} + 3\ \text{Hz} = 352$ Hz or
$f_2 = f_1 - f_{beat} = 349\ \text{Hz} - 3\ \text{Hz} = 346$ Hz.

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1. Andrew hears the sound of the firing of a distant cannon 6.00 s after seeing the flash. How far from the cannon is Andrew?

$d = v_s t = (343\ \text{m/s})(6.00\ \text{s}) = 2.06 \times 10^3$ m

2. A rifle is fired in a valley with parallel vertical walls. The echo from one wall is heard 2.0 s after the rifle was fired. The echo from the other wall is heard 2.0 s after the first echo. How wide is the valley?

The time it takes sound to go to wall 1 and back is 2.0 s. The time it takes to go to the wall is half the total time or 1.0 s,
$d_1 = v_s t_1 = (343\ \text{m/s})(1.0\ \text{s}) = 3.4 \times 10^2$ m.
The total time for the sound to go to wall 2 is half of 4.0 s or 2.0 s.
$d_2 = v_s t_2 = (343\ \text{m/s})(2.0\ \text{s}) = 6.8 \times 10^2$ m.
The total distance is $d_1 + d_2 = 1.02 \times 10^3$ m.

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3. If Karen claps her hands and hears the echo from a distant wall 0.20 seconds later, how far away is the wall?

The total distance = vt = (343 m/s)(0.20 s) = 68.6 m, so the distance to the wall is half this, or 34 m.

4. If Karen shouts across a canyon and hears an echo 4.00 seconds later, how wide is the canyon?

$d = vt$ = (343 m/s)(4.00 s) = 1372 m is the total distance travelled. The distance to the wall is $\frac{1}{2}(1372)$ = 686 m.

5. A certain instant camera determines the distance to the subject by sending out a sound wave and measuring the time needed for the echo to return to the camera. How long would it take the sound wave to return to the camera if the subject were 3.00 m away?

The total distance the sound must travel is 6.00 m.

$d = vt$, so

$$t = \frac{d}{v} = \frac{(6.00\ \text{m})}{(343\ \text{m/s})} = 0.0175\ \text{s.}$$

6. Carol drops a stone into a mine shaft 122.5 m deep. How soon after she drops the stone does she hear it hit the bottom of the shaft?

First find the time it takes the stone to fall down the shaft by $d = \frac{1}{2}gt^2$, so

$$t = \sqrt{\frac{d}{\frac{1}{2}g}} = \sqrt{\frac{-122.5}{\frac{1}{2}(-9.80)}} = 5.00\ \text{s.}$$

The time it takes the sound to come back up is found with $d = v_s t$, so

$$t = \frac{d}{v_s} = \frac{122.5\ \text{m}}{343\ \text{m/s}} = 0.36\ \text{s.}$$

The total time is 5.00 s + 0.36 s = 5.36 s.

7. If the wavelength of a 4.40×10^2 Hz sound in fresh water is 3.30 m, what is the speed of sound in water?

$$v = f\lambda = (4.40 \times 10^2\ \text{Hz})(3.30\ \text{m}) = 1.45 \times 10^3\ \text{m/s}$$

8. Sound with a frequency of 442 Hz travels through steel. A wavelength of 11.66 m is measured. Find the speed of the sound in steel.

$$v = f\lambda = (442\ \text{Hz})(11.66\ \text{m}) = 5.15 \times 10^3\ \text{m/s}$$

9. The sound emitted by bats has a wavelength of 3.5 mm. What is its frequency in air?

$$f = \frac{v}{\lambda} = \frac{(343\ \text{m/s})}{(0.0035\ \text{m})} = 9.8 \times 10^4\ \text{Hz}$$

10. Ultrasound with a frequency of 4.25 MHz can be used to produce images of the human body. If the speed of sound in the body is the same as in salt water, 1.50 km/s, what is the wavelength in the body?

$v = \lambda f$, so

$$\lambda = \frac{v}{f} = \frac{(1.50\ \text{km/s})(1000\ \text{m/km})}{(4.25 \times 10^6\ \text{Hz})} = 3.53 \times 10^{-4}\ \text{m}$$

11. The equation for the Doppler shift of a sound wave of speed v, reaching a moving detector, is $f' = f\left[\frac{v + v_d}{v - v_s}\right]$, where v_d is the speed of the detector and v_s is the speed of the source; f' is the frequency at the detector. If the detector moves toward the source, v_d is positive and if the source moves toward the detector v_s is positive. A train moving toward a detector at 31 m/s blows a 305-Hz horn. What is detected by a

a. stationary train?

$$f' = f\left[\frac{v + v_d}{v - v_s}\right] = \frac{(305\ \text{Hz})(343\ \text{m/s} + 0)}{(343\ \text{m/s} - 31\ \text{m/s})} = 340\ \text{Hz}$$

b. train moving toward the first train at a speed of 21 m/s?

$$f' = f\left[\frac{v + v_d}{v - v_s}\right] = \frac{(305\ \text{Hz})(343\ \text{m/s} + (21\ \text{m/s}))}{(343\ \text{m/s} - 31\ \text{m/s})} = 360\ \text{Hz}$$

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12. The train in the previous problem is moving away from the detector. Now what frequency is detected by a

a. stationary train?

$$\begin{aligned} f' &= f\left[\frac{v + v_d}{v - v_s}\right] \\ &= (305\ \text{Hz})\left[\frac{343\ \text{m/s} + 0}{343\ \text{m/s} - (-31\ \text{m/s})}\right] \\ &= 280\ \text{Hz} \end{aligned}$$

b. train moving away from the first train at 21 m/s?

$$\begin{aligned} f' &= f\left[\frac{v + v_d}{v - v_s}\right] \\ &= (305\ \text{Hz})\left[\frac{343\ \text{m/s} + (-21\ \text{m/s})}{343\ \text{m/s} - (-31\ \text{m/s})}\right] \\ &= 263\ \text{Hz} \end{aligned}$$

13. A slide whistle has a length of 27 cm. If you want to play a note one octave higher, how long should the whistle be?

$\lambda = \frac{4L}{3} = \frac{4(27\ \text{cm})}{3} = 36$ cm. A note one octave higher is the first overtone of the fundamental. Resonances are spaced by $\frac{1}{2}$ wavelength. Since the original whistle length of 27 cm = $\frac{3}{4}$ the wavelength of the first overtone (octave), then the shortest whistle length for the first overtone equals

$\frac{3\lambda}{4} - \frac{\lambda}{2} = \frac{\lambda}{4} = \frac{36\ \text{cm}}{4} = 9$ cm

14. Adam, an airport worker working near a jet plane taking off, experiences a sound level of 150 dB.

a. If Adam wore ear protectors that reduce the sound level to that of a chain saw, what decrease in dB would be required?

Chain saw is 110 dB, so 40 dB reduction is needed.

b. If Adam now heard something that sounded like a whisper, what would a person not wearing the protectors hear?

A soft whisper is 10 dB, so the actual level would be 50 dB, or that of an average classroom.

15. A rock band plays at an 80-dB sound level. How many times greater is the sound pressure from another rock band playing at

a. 100 dB?

Each 20 dB increases pressure by a factor of 10, so

10 dB.

b. 120 dB?

100 dB

16. An open vertical tube is filled with water and a tuning fork vibrates over its mouth. As the water level is lowered in the tube, resonance is heard when the water level has dropped 17 cm, and again after 49 cm of distance exists from the water to the top of the tube. What is the frequency of the tuning fork?

49 cm − 17 cm = 32 cm, or 0.32 m. Since the tube is closed at one end, $\frac{1}{2}\lambda$ exists between points of resonance.

$\frac{1}{2}\lambda = 0.32$ m, so $\lambda = 0.64$ m

$f = \frac{v}{\lambda} = \frac{343\ \text{m/s}}{0.64\ \text{m}} = 540$ Hz

17. If you hold a 1.0-m metal rod in the center and hit one end with a hammer, it will oscillate like an open pipe. Antinodes of air pressure correspond to nodes of molecular motion, so there is a pressure antinode in the center of the bar. The speed of sound in aluminum is 5150 m/s. What would be the lowest frequency of oscillation?

The rod length is $\frac{1}{2}\lambda$, so $\lambda = 2.0$ m,

$f = \frac{v}{\lambda} = \frac{(5150\ \text{m/s})}{(2.0\ \text{m})} = 2.6$ kHz.

18. The lowest note on an organ is 16.4 Hz.

a. What is the shortest open organ pipe that will resonate at this frequency?

$$\lambda = \frac{v}{f}$$

$$= \frac{(343\ \text{m/s})}{(16.4\ \text{Hz})} = 20.9\ \text{m}$$

$$l = \frac{\lambda}{2}$$

$$= \frac{(20.9\ \text{m})}{(2)} = 10.5\ \text{m}$$

b. What would be the pitch if the same organ pipe were closed?

$$f_c = \frac{f_0}{2}$$

$$f_c = \frac{(16.4\ \text{Hz})}{2} = 8.20\ \text{Hz}$$

19. During normal conversation the amplitude of the pressure wave is 0.020 N/m^2.

a. If the area of the eardrum is 0.52 cm^2, what is the force on the eardrum?

$$F = pA = (0.020\ \text{N/m}^2)(0.52 \times 10^{-4}\ \text{m}^2)$$
$$= 1.0 \times 10^{-6}\ \text{N}$$

b. The mechanical advantage of the bones in the inner ear is 1.5. What force is exerted on the oval window?

$$(1.5)(1.0 \times 10^{-6}\ \text{N}) = 1.5 \times 10^{-6}\ \text{N}$$

c. The area of the oval window is 0.026 cm^2. What is the pressure increase transmitted to the liquid in the cochlea?

$$p = \frac{F}{A} = \frac{(1.5 \times 10^{-6}\ \text{N})}{(0.026 \times 10^{-4}\ \text{m}^2)} = 0.58\ \text{N/m}^2$$

20. One tuning fork has a 445-Hz pitch. When a second fork is struck, beat notes occur with a frequency of 3 Hz. What are the two possible frequencies of the second fork?

445 Hz − 3 Hz = 442 Hz and
445 Hz + 3 Hz = 448 Hz

21. A flute acts like an open pipe and sounds a note with a 370-Hz pitch. What are the frequencies of the second, third, and fourth harmonics of this pitch?

$2f = (2)(370\ \text{Hz}) = 740\ \text{Hz}$
$3f = (3)(370\ \text{Hz}) = 1100\ \text{Hz}$
$4f = (4)(370\ \text{Hz}) = 1500\ \text{Hz}$

22. A clarinet sounds the same note as the flute in the previous problem, 370 Hz. However, it only produces harmonics that are odd multiples of the fundamental frequency. What are the frequencies of the lowest three harmonics produced by the clarinet?

$3f = (3)(370\ \text{Hz}) = 1100\ \text{Hz}$
$5f = (5)(370\ \text{Hz}) = 1900\ \text{Hz}$
$7f = (7)(370\ \text{Hz}) = 2600\ \text{Hz}$

23. One closed organ pipe has a length of 2.40 m.

a. What is the frequency of the note played by this pipe?

$\lambda = 4l = (4)(2.40\ \text{m}) = 9.60\ \text{m}$
$v = f\lambda$

$$f = \frac{v}{\lambda} = \frac{343\ \text{m/s}}{9.60\ \text{m}} = 35.7\ \text{Hz}$$

b. When a second pipe is played at the same time, a 1.40 Hz beat note is heard. By how much is the second pipe too long?

$f = 35.7\ \text{Hz} - 1.40\ \text{Hz} = 34.3\ \text{Hz}$
$v = f\lambda$

$$\lambda = \frac{v}{f} = \frac{343\ \text{m/s}}{34.3\ \text{Hz}} = 10.0\ \text{m}$$

$\lambda = 4l$

$$l = \frac{\lambda}{4} = \frac{10.0\ \text{m}}{4} = 2.50\ \text{m}$$

The difference in lengths is 2.50 m − 2.40 m = 0.10 m.

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24. One organ pipe has a length of 836 mm. A second pipe should have a pitch one major third higher. How long should this pipe be?

$$L = \frac{\lambda}{2}, \text{ so } \lambda = 2L; \text{ and } v = f\lambda, \text{ so } f = \frac{v}{2L}$$

$$= \frac{(343 \text{ m/s})}{(2)(0.836 \text{ m})} = 205 \text{ Hz.}$$

The ratio of a frequency one major third higher is 5:4, so $(205 \text{ Hz})\left[\frac{5}{4}\right] = 256 \text{ Hz.}$

The length of the second pipe is

$$L = \frac{v}{2f} = \frac{(343 \text{ m/s})}{(2)(256 \text{ Hz})} = 670 \text{ mm.}$$

25. The Doppler shift was first tested in 1845 by the French scientist B. Ballot. He had a trumpet player sound an A, 440 Hz, while riding on a flatcar pulled by a locomotive. At the same time, a stationary trumpeter played the same note. Ballot heard 3.0 beats per second. How fast was the train moving toward him?

440 Hz + 3.0 Hz = 443 Hz

$$f' = f\left[\frac{(v + v_d)}{(v - v_s)}\right] \text{ so } (v - v_s)f' = (v + v_d)f \text{ and}$$

$$v_s = v - \frac{(v + v_d)f}{f'}$$

$$= (343 \text{ m/s}) - \frac{(343 \text{ m/s} - 0)(440 \text{ Hz})}{443 \text{ Hz}}$$

$$= 2.3 \text{ m/s}$$

26. A student wants to repeat Ballot's experiment. She plans to have a trumpet played in a rapidly moving car. Rather than listening for beat notes, she wants to have the car move fast enough so the moving trumpet sounds a major third above a stationary trumpet.

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a. How fast would the car have to move?

major third ratio = 5:4

$$f' = f\left[\frac{(v + v_d)}{(v - v_s)}\right] \text{ so}$$

$$(v - v_s)f' = (v + v_d)f \quad \text{and}$$

$$v_s = v - \frac{(v + v_d)f}{f'} = v - (v + v_d)\frac{f}{f'}$$

$$= (343 \text{ m/s}) - (343 \text{ m/s} - 0)\left[\frac{5}{4}\right]$$

$$= 69 \text{ m/s} = 250 \text{ km/h}$$

b. Should she try the experiment?

No, do not try the experiment.

Supplemental Problems (Appendix B)

1. The echo of a ship's fog horn, reflected from an iceberg, is heard 5.0 s after the horn is sounded. How far away is the iceberg?

$d = vt$, where $t = \frac{5.0 \text{ s}}{2} = 2.5$ s, since sound must travel to the iceberg and back.
$d = vt = (343 \text{ m/s})(2.5 \text{ s}) = 8.6 \times 10^2 \text{ m}$

2. What is the speed of sound that has a frequency of 250 Hz and a wavelength of 0.600 m?

$v = \lambda f = (0.600 \text{ m})(250 \text{ Hz}) = 150 \text{ m/s}$

3. A sound wave has a frequency of 2000 Hz and travels along a steel rod. If the distance between successive compressions is 0.400 m, what is the speed of the wave?

$v = \lambda f = (0.400 \text{ m})(2000 \text{ Hz}) = 800 \text{ m/s}$

4. What is the wavelength of a sound wave that has a frequency of 250 Hz and a speed of 400 m/s?

$$\lambda = \frac{v}{f} = \frac{(400 \text{ m/s})}{(250 \text{ Hz})} = 1.60 \text{ m}$$